Switching Between Taxonomic and Thematic Semantic Processing

A Thesis

Submitted to the Faculty

of

Drexel University

by

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In partial fulfillment of the

requirements for the degree

of

Masters of Psychology

June 2016

Contents

List of Tables

List of Figures

Abstract

Switching Between Taxonomic and Thematic Semantic Processing

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The present project had two distinct goals. One was to develop and provide a large set of normed materials of taxonomic and thematic word pairs for future studies to utilize. The second goal of the present project was to test predictions about the underlying mechanisms responsible for taxonomic and thematic semantic processing made by the distributed plus-hub and dual-hub theories of semantic memory. This was done using triads and oddball semantic judgment tasks to test for a taxonomic-thematic switch cost. The presence of a switch cost would fall in line with the dual-hub theory where it is posited that taxonomic and thematic semantics are processed independently and therefore when switching between the judgments a behavioral or in the case of the present studies a reaction time cost would appear. The results of the triads and oddball switch cost studies fall in line with the dual-hub theory of semantics, as regardless of the direction of the switch (i.e. taxonomic to thematic or thematic to taxonomic) reaction times were slower when compared to making sequential judgments of the same type.

Section 1. Introduction

Semantic memory is one of the most crucial aspects of human cognition. It is the foundation of our knowledge, plays a role in understanding language, allows us to interact with objects and even plays a role in future thinking (Buxbaum & Saffran, 2002; Irish, Addis, Hodges, & Piguet, 2012; McRae & Jones, 2013). Although researchers have been investigating semantic memory for years there is still disagreement among theories in regards to its representation and organization. For instance while some believe that semantic memory relies on amodal representations others contend that it is represented by the specific sensory and motor features of the concepts themselves (Allport, 1985; Binder, Desai, Graves, & Conant, 2009; Gainotti, 2011; Meyer & Damasio, 2009). These theories have led to various models of semantic memory including hierarchical models (McClelland & Rogers, 2003), that tend to rely on the features of concepts, placing them into discrete categories, and network based models that link items together based on their relations and/or associations to each other (Deyne, Verheyen, Perfors, & Navarro, 2015; Nelson, McEvoy, & Dennis, 2000). However although these models can explain various phenomena relating to semantic memory they tend to have difficulty generalizing across the various functions of semantic memory.

For example although feature based hierarchical models are ideal for object identification, as correct identification relies on parsing apart features, they are not as good at explaining relations between concepts. This is because these models rely on perceptual features and it is not clear how perceptual features can explain event based relations between concepts. Conversely network based models of semantic memory are good at explaining relations and/or associations between concepts but underspecify the type of relations (i.e. feature based or event based) and therefore may not be as optimal for categorical based judgments. This dichotomy in model architecture presents a weakness given that feature parsing and/or categorization and identifying relations between objects are both important functions of semantic memory. Therefore a more complete model of semantic memory should be able to account for both feature and relation based semantics. Moreover the issue of model generalization is prevalent in research of taxonomic and thematic semantics.

Taxonomic knowledge is defined as items within the same category and/or items that share similar features (i.e. color, shape, size and etc.). For example a *PALM-TREE* and a *PINE-TREE* can be considered taxonomically related as they share similar features and belong to the plant and/or tree category. Therefore this type of knowledge aligns well with hierarchical models of semantic memory as it places a strong emphasis on category membership by shared features as opposed to relational links. On the other hand, thematic knowledge is defined as items that co-occur in time and/or place but which do not share similar features. For example, *DOG* and *LEASH* are considered thematically related as they co-occur in the same event (i.e. walking a dog) however they do not share similar features and would not be considered taxonomically related (Deyne et al., 2015; Kalénine, Mirman, Middleton, & Buxbaum, 2012; Lin & Murphy, 2001; Mirman & Graziano, 2013; Schwartz et al., 2011). This type of knowledge therefore fits more appropriately with network based models of semantics as it places an emphasis on relationships between concepts. However, as previously discussed neither hierarchical models nor network based models seem optimal for explaining both taxonomic and thematic semantics, as they have difficulty when generalizing across functions. Therefore a model of semantics that can account for both types of relations is needed. Currently two theories and/or models of semantics, have made distinct claims regarding taxonomic and thematic processing.

The distributed plus-hub model originally introduced by Rogers et al., in 2004, contends that although semantic knowledge is broken down and stored as perceptual components, a single system and/or hub is responsible for the processing of this information and therefore handles all higher level semantic functions including taxonomic and thematic processing. Evidence for this model originally came from neuropsychological investigations of semantics but has also more recently been supported by a study using fMRI that investigated taxonomic and thematic semantics (Au, Chan, & Chiu, 2003; Catricalà et al., 2015; Domoto-Reilly, Sapolsky, Brickhouse, & Dickerson, 2012; Hoffman, Jones, & Ralph, 2012; Jackson, Hoffman, Pobric, & Ralph, 2015; Jefferies, Patterson, & Ralph, 2008; Merck, Jonin, Laisney, Vichard, & Belliard, 2014; Patterson, Nestor, & Rogers, 2007). This model of semantic memory however seems to underplay the distinction between taxonomic and thematic relationships and the types of comparisons which are necessary to make these judgments. Therefore much like in the previous discussion of hierarchical and network based model, this model also seems to fall short in accounting for the computational differences between taxonomic and thematic semantics. More recently however the dual-hub theory of semantic processing has also made distinct claims about semantic processing and appears to be able to handle the taxonomic thematic distinction.

Evidence of the dual-hub theory originally came from an analysis of aphasic picture naming errors where they found that taxonomic errors (i.e. given picture of a *DOG* and responded *CAT*), while controlling for thematic errors, correlated with damage in the anterior temporal lobe (ATL), whereas thematic errors (i.e. given picture of *DOG* and responded *LEASH*), while controlling for taxonomic errors, correlated with damage to the temporoparietal cortex (TPC). Hence the authors claimed that while the ATL was responsible for taxonomic processing the TPC was responsible for thematic processing (Schwartz et al., 2011). Suggesting that more than one system may be responsible for the processing of semantic knowledge. Given the differences between taxonomic and thematic semantics a dual-hub model seems more appropriate for handling and/or generalizing across both taxonomic and thematic related processing. Further evidence of a dual system model of semantic processing has come from recent neurological investigations (Chen et al., 2014; Geng & Schnur, 2016; Lewis, Poeppel, & Murphy, 2015; Maguire, Brier, & Ferree, 2010; Mirman & Graziano, 2013) and also from a long history of behavioral evidence, which has shown differences in the processing of taxonomic and thematic semantics.

One such study performed by Mirman and Graziano in 2012 utilized eye tracking during a spoken word to picture matching task followed by a similarity judgment task to investigate differences in taxonomic and thematic processing. The authors found that although the competition effect of taxonomic items was larger, thematic relations were also activated during spoken word comprehension. It was also found that individuals' relative activation predicted their tendency to select one relation over the other in the similarity judgment task. This showed that thematic relations are activated even when the task did not explicitly call for it and also suggests that there is individual variability in an individual's reliance on these relation types (Mirman & Graziano, 2012). These results also continue to suggest that there are two separable systems responsible for taxonomic and thematic processing because the taxonomic competition effect was larger than the thematic competitors effect and if it is presupposed that these relations are processed in the same system then the observed difference between the activation of taxonomic competitors and thematic competitors may not have been as great and/or exist at all. Similarly in another eye tracking study done investigating differences in thematic, specific functions, and general functions (functions were taxonomically similar) in manipulable objects it was found that without context there was earlier and shorter activation of thematically related items as compared to the other relation types (Kalénine et al., 2012). Once again suggesting differences in processing mechanisms responsible for these types of relations as if they relied on the same system then there would not have been differences between the onset of activation between thematic and specific functions.

Further in a study performed by Jones and Golonka in 2012, participants performed a simple lexical decision task where the relationship between words was manipulated to be taxonomic, thematic or combinatorial (i.e. fruit and cake or fruitcake). The authors also manipulated the stimulus onset asynchrony (SOA) and used different measures of word pair relatedness (including latent semantic analysis (LSA) and the log number of Google hits) in order to see if any processing differences existed. Overall the magnitude and amount of activation across the three types of relations were similar when looking at reaction times (RT) and priming effects but some differences were found when SOA were varied and the different measures of word pair relationships used also differently predicted RT's across SOA's (Jones & Golonka, 2012). Furthering the argument for differences in taxonomic and thematic processing as if a single system was responsible for processing these knowledge types it is hard to predict why simply varying the SOA would cause differences in RT's.

Finally, evidence for distinct taxonomic and thematic systems has come from developmental and aging literature. In four studies researchers investigated the ability of young children and older adults to switch between categorizing strategies. The authors of these studies found that both young children and older adults have trouble switching between categorization strategies (Blaye, Bernard-Peyron, Paour, & Bonthoux, 2006; Blaye, Chevalier, & Paour, 2007; Maintenant, Blaye, & Paour, 2011; Maintenant, Blaye, Pennequin, & Paour, 2013). The problems exhibited by the young children and older adults, suggest that the cognitive processes involved in making the relational judgments necessary to successfully complete the tasks and or switch to a different categorization type (i.e. taxonomic or thematic) needed to be differentially activated. Where as if they were processed by the same cognitive system then one would not expect to see any type of switch cost to appear, as there would be no difference in the processing required to make the judgments. Moreover although these studies revealed costs when switching between categorization strategies in young children and older adults, there is little evidence of a cost due to processing requirements among young adults.

This could be due to multiple reasons including the explicit nature of most categorization tasks. In general categorization tasks explicitly ask participants to place items into categories of one type or another and because young adults can pick up on both type of relations it would be hard to expect any type of switch cost to appear. Thus one goal of the current project was to investigate if young adults exhibit a switch cost at an implicit level when grouping items together, which would add evidence to the fact that taxonomic and thematic semantic processing requires complementary but distinct systems.

Section 1.1. Norming of taxonomic and thematic materials

Currently in the field there is a lack of consistency in terms of how materials are gathered, defined, and normed. For example although some authors define taxonomic relationships based on feature similarity, others define it based on biological hierarchies. While for thematic relations while some authors have used latent semantic analysis to determine thematic pairs, others have used expert opinion based on their own definitions such as co-occurrence in an event (Au et al., 2003; Baldwin, 1992; Davidoff & Roberson, 2004; Fenson, Vella, & Kennedy, 1989; Imai, Saalbach, & Stern, 2010; Jackson et al., 2015; Lewis et al., 2015; Maguire et al., 2010). An example where these differences can become problematic is found when trying to determine if a *CAT* and *DOG* are taxonomically or thematically related. Based on a biological hierarchy it would depend how high on the tree one went, as under the general animal umbrella they are related taxonomically but further down the trees they are not which could lead authors to making them thematically related based on their co-occurrence in events (i.e. in a house). This becomes problematic because without a consistent definition for the items it will create noise in results across studies. Furthermore some of these differences in definitions and norming methods are present in three of the above mentioned studies.

In the Jackson et al (2015) fMRI study they used LSA on a large corpus to generate a matrix containing frequency of co-occurrences. They then used decomposition values to find a single thresholding value. Pairs of items having a score of 0.2 or higher were considered to be associated and those below 0.2 were considered not to be associated. Finally they separated pairs into taxonomic or thematic pairs based on expert judgment. Items considered to be thematically associated needed to share few similar conceptual features and or come from different domains, where as conceptually similar targets or taxonomic pairs had to come from the same semantic category (Jackson et al., 2015).

In Lewis et al's (2015) MEG study the authors collaborated to create their item pairs based on an agreed upon definition of taxonomic and thematic relations and then obtained the association strengths for all their pairs to make sure that association levels were low. Finally in the Maguire et al (2010) study they created a set of taxonomically and thematically related pairs and then had a group of students "knowledgeable about semantics" go through and select the taxonomic, thematic and unrelated items relative to the given target, in order to see if there was general agreement amongst the students and authors as to which items were taxonomically, thematically or unrelated to the targets.

Thus as can be seen from these three cases alone there is no consensus in regards to the best way to obtain and norm items for experiments. These differences in norming procedures may contribute to the conflicting results discussed. This is because with slightly different definitions of what qualifies as a taxonomic relationship and what qualifies as a thematic relationship and no consistent set of items, it is hard to expect that there would be any converging results between studies. This is also due in part because in prior studies it has been shown that there is variability in terms of reliance on and the effect of taxonomic and thematic relations at the individual level, which may blur results within studies (Mirman & Graziano, 2012; Simmons & Estes, 2008). Thus with individual variability playing a role within studies themselves, adding inconsistent materials will only further confound results between studies.

Section 1.3. Goals and Hypotheses

The goals for this research project were twofold. First it was to provide a large set of normed word pairs that can be used in future studies of taxonomic and thematic semantics. As well as to provide a basis of norming that future studies can utilize to add to the norms. The second goal of the present project was to test whether, as predicted by the dual-hub theory, switching between taxonomic and thematic relations involves switching between distinct cognitive/neural systems. To accomplish these goals, first a large scale norming study was carried out to establish the taxonomic and thematic relations in materials from prior studies of taxonomic and thematic systems. Then, following from a line of work that investigated the embodied theory of cognition by employing a switch cost paradigm (Pecher, Zeelenberg, & Barsalou, 2003), triads and oddball semantic judgment tasks were employed to test for a taxonomic-thematic switch cost in order to determine if the taxonomic and thematic systems are processed together or independently.

Section 2. Studies

Section 2.1. Taxonomic and Thematic Word Pair Norms

Methods

Participants

157 total participants were recruited using Amazon's Mechanical Turk services. In order for a participant's data to be included in the final analysis they had to meet the following criteria:

1) Be a current resident of the United States of America
2) Either be a native English speaker or have learned English before the age of 5.
3) Primarily speak English at home and their place of employment
4) Have a high school education or higher.

Upon completion of the survey, participants who answered at least 95% of the questions were compensated for their participation. Participants were only allowed to complete one of the four total surveys.

Materials

Taxonomic and thematic word pairs were gathered from previously published studies (Jackson et al., 2015; Lewis et al., 2015; Maguire et al., 2010) and were then combined with the previously normed items created for the triads switch cost study. In all there were a total of 300 target words paired with taxonomically related and/or thematically related words for a total of 659 word pairs.

Procedure

Norming surveys were created on and hosted by the Qualtrics online survey services website as well as on Survey Monkey. Using 7 point Likert scales, each word pair was placed in a taxonomic rating survey and a thematic rating survey. Although there were multiple surveys used in order to shorten individual survey length, the instructions for all of the surveys were the same depending on the type of survey:

Taxonomic Instructions:

"Thank you for participating. In this survey you will be presented with a number of word pairs and asked to rate the similarity of the two words on a scale from 1 (not at all similar) to 7 (very similar). Using the radio buttons below each word pair select 1, 2, 3, 4, 5, 6, or 7 to rate the similarity between the words. Two words are similar if they look alike or belong to the same category. For example, DOTS and STRIPES are similar (both are types of patterns or designs). However, SHIRT and STRIPES would not be similar. Even though STRIPES are often found on SHIRTS, a SHIRT is a type of clothing while STRIPES are not. Another example is ZEBRA and STRIPES, these two words are also not very similar, because they belong to different categories, animal and pattern categories respectively. Please use the full range of the scale (1, 2, 3, 4, 5, 6, or 7) in indicating your responses. Only the buttons below the word pair will work for rating the items. Please make sure to rate all the pairs in the survey."

Thematic Instructions:

"Thank you for participating. In this survey you will be presented with a number of word pairs and asked to rate how connected and or related the two words are on a scale from 1(not related at all) to 7 (very related). Using the radio buttons below each word pair select 1, 2, 3, 4, 5, 6 or 7 to rate the relatedness between the two words. Two words are connected or related if they occur in the same time or place, however, this does not mean they will share similar physical features. For example HELMET and MOTORCYCLE are related (one wears a HELMET while riding a MOTORCYCLE, although they are different shapes and sizes). Whereas CHRISTMAS-TREES and PALM-TREES are not related, because even though they are both trees and share similar features they do not occur in the same time or place. Please use the full range of the scale (1, 2, 3, 4, 5, 6, or 7) in indicating your responses. Only the buttons below the word pair will work for rating the items. Please make sure to rate all the pairs in this survey."

All pairs, regardless of whether or not they were meant to be a taxonomic or a thematic pair, were normed for both taxonomic and thematic relatedness. For each pair, a difference score was then calculated by subtracting the mean thematic relatedness rating from the mean taxonomic similarity rating for each word pair. Thus items with high taxonomic similarity and low thematic relatedness have positive difference scores (6 being the highest); items with negative scores have high thematic relatedness and low taxonomic similarity (-6 being the highest); pairs with difference scores near 0 are approximately equally taxonomically similar and thematically related (this includes both approximately equally high and equally low ratings). The participants' individual ratings of word pairs were also provided in a separate data table. This table includes participant id numbers and basic demographic information for each participant (i.e. gender, age, native language and etc.). It also provides the rating given for each pair and the type of rating that it was (i.e. taxonomic or thematic). In total there are 27,317 individual word pair ratings provided in this table.

Ref_Word	Pair_Word	Mean_Rating_Tx	SD_Rating_Tx	Mean_Rating_Thm	SD_Rating_Thm	Difference_Score	Num_Ratings_Tx	Num_Ratings_Thm
BIRD	LAMB	2.95	1.94	2.84	1.92	0.11	21	19
SHOP	MARKET	5.71	1.74	6	1.53	-0.29	21	18
HOOVER	MOWER	3	2.05	2.32	1.6	0.68	21	19
VASE	BUCKET	4.57	1.72	2.63	1.86	1.94	21	19
APPLE	LIME	4.62	1.88	3.79	1.69	0.83	21	19
EXAM	PROGRAMME	3.14	1.96	3.58	1.95	-0.44	21	19
GRAFFITI	POSTER	3.67	1.93	3.95	2.15	-0.28	21	19

Table 1. First 8 rows of the taxonomic and thematic word pair norms.

ID	Gender	Age	Level_of_ Education	First_Language	Age_Learned_English_If_Not _Native	Country_Living_In	Ref_Word	Pair_Word	Rating	Rating_Type
id1	F	19	High School or below	Russian	3	US	BIRD	LAMB	4	Taxonomic
id1	F	19	High School or below	Russian	3	US	SHOP	MARKET	7	Taxonomic
id1	F	19	High School or below	Russian	3	US	HOOVER	MOWER	5	Taxonomic
id1	F	19	High School or below	Russian	3	US	VASE	BUCKET	6	Taxonomic
id1	F	19	High School or below	Russian	3	US	APPLE	LIME	6	Taxonomic
id1	F	19	High School or below	Russian	3	US	EXAM	PROGRAMM E	3	Taxonomic

Table 2. First 8 rows of the individual participant ratings table.

Section 2.2. Switch Cost Experiments

Motivation for the switch cost studies comes primarily from the dual-hub hypothesis of semantic processing. As discussed previously the dual-hub model of sematic processing posits that there are two separate systems and/or hubs responsible for semantic processing. One system responsible for taxonomic processing and the other responsible for thematic processing (Schwartz et al., 2011). Therefore it would be expected that switching between the processing of these relation types could elicit a switch cost. Similar thinking has been used in investigations of the embodied theory of cognition. In a study performed by Pecher and colleagues (2003), they found that switching between sensory modalities in a feature verification task elicited a switch cost. The authors claimed that this provided evidence for switching between the systems responsible for re-enacting the sensory modalities in order to do the verification task (Pecher et al., 2003). Hence, following from this study if switching between taxonomic and thematic processing elicits a reaction time cost then it would provide evidence for switching between the respective systems.

Section 2.3. Experiment 1 – Triads

2.3.1. Methods

Participants

32 participants were recruited from Drexel University (8 males and 24 females). The mean age of the participants was 19.9 years old (*SD* = 1.8). All participants were native English speakers or native bilingual English speakers who had learned English by the age of 5 years old. All participants provided informed consent and were compensated with course credit for their participation. No participant exclusions occurred.

Materials

Word pairs were generated as either being taxonomically similar or thematically related using the definitions described above. The method for norming the word pairs were the same as discussed in section 2.1. It is worth noting that the mean difference scores of the taxonomic word pairs (M = 1.55, SD = .56) were significantly less then the mean difference scores for the thematic word pairs (M = 2.90, SD = .78) ($t(84) = -9.72$, $p < .001$). The taxonomic and thematic items were shuffled to become unrelated items associated with a different target and these pairs were normed using the same method as discussed to make sure no unforeseen relationships existed. This shuffling was done to control for other properties of the words that may affect the task, thus all taxonomic items appeared as both a taxonomically related item to its target word and as the unrelated item to a different target and the same was done for thematic items. All conditions were also matched in terms of their length in letters and phonemes (obtained from the Speech and Hearing Lab Neighborhood Database, 2014), word frequency (obtained from the *Subtlex* US database for reference see Brysbaert & New, 2009), and orthographic neighborhood sizes (obtained from the *ClearPond* database for reference see Marian, Bartolotti, Chabal, & Shook, 2012)

Mean	Similarity Rating	Relatedness Rating	Difference Score
Taxonomic	4.76	3.23	1.55
Thematic	2.89	5.79	2.90

Table 3. Mean taxonomic similarity and relatedness ratings for the taxonomic and thematic word pairings.

Four lists were created consisting of two blocks each. Lists were counterbalanced so that each item appeared in both taxonomic and thematic trials and as same (taxonomic to taxonomic or thematic to thematic) and switch trials (taxonomic to thematic defined as a thematic switch trial or thematic to taxonomic defined as a taxonomic switch trial). Each target word appeared once in a block. Within a single list, each target word was presented in a taxonomic trial in one block and in a thematic trial in the other block; the same/switch counterbalancing was done across lists (and, thus, across participants). In sum, each list contained 96 trials in a 2 (trial type: taxonomic vs. thematic) by 2 (task type: same vs. switch) design with 24 trials in each cell of the design. Participants were randomly assigned to 1 of the 4 total lists resulting in 8 participants completing each list.

Procedure

Participants started by filling out a brief background survey and then began the experiment. The experiment was run using PsychoPy where the reaction time and accuracy for each trial was recorded. The instructions given to each participant were to select the word that was most related to the word at the top of the screen by pressing Z for the word on the bottom left and M for the word on the bottom right. Reaction time recordings began at the presentation of the words with an inter-trial interval (ITI) of 500 ms between individual trials. After completing 5 practice trials where feedback was given, participants were told the experiment would begin and no more feedback would be given. However, the next 5 trials were filler trials (not analyzed) to allow for further practice and to allow the participants to be performing optimally on all analyzed trials. Midway through the experimental list of trials (between the two blocks) there was a break provided. The first trial after the midway break was excluded as it was neither a same nor a switch trial. For an example of a trial sequence see figure 1.

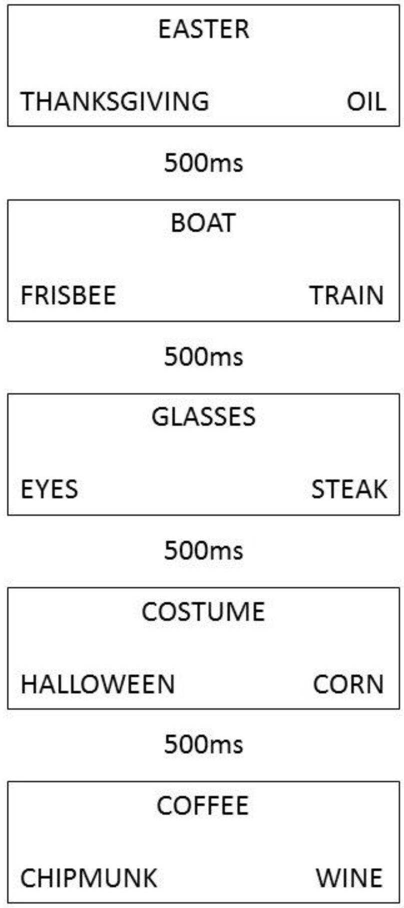

Figure 1. Example timeline of trials. Each box represents a single trial with a 500ms ITI in between trials. The first (EASTER-THANKSGIVING) and second (BOAT-TRAIN) trials are taxonomic trials and thus the second trial is considered a taxonomic same trial. The third trial (GLASSES-EYES) is a thematic trial and therefore is considered a thematic switch trial. The fourth trial (COSTUME-HALLOWEEN) in the sequence is also a thematic trial and is therefore a thematic same trial. The final trial (COFFEE-WINE) is once again a taxonomic trial and thus is a taxonomic switch trial.

2.3.2. Analysis and Results

Reaction Time Analysis

Data were analyzed using the statistical tools provided by R version 3.1.2 (R Core Team, 2014). Reaction times of incorrect trials and trials where the reaction time was less than 250 ms were excluded from the analysis. The subsequent trial after these trials were also excluded because if the participant got a trial wrong or hit the button before actually processing the stimuli, then it was assumed they did not understand the probed relationship and thus the subsequent trial would neither be a same nor a switch trial. These exclusion criteria resulted in a total of 218 out of the original 3072 experimental trials (7%) being dropped from further analysis. Trials with the target item *WAGON* were excluded due to poor overall accuracy (69%) across participants (N = 44 trials). No participants were excluded due to poor overall accuracy (M = 0.96, SD = 0.03). After making data exclusions, the total number of remaining observations was 2810. Using the lme4 package version 1.1-7, a linear mixed effects model was employed to analyze the raw reaction time data per trial (Baayen, Davidson, & Bates, 2008). The model included fixed effects of trial type (taxonomic or thematic) and task type (same or switch) along with random effects of trial type by reference word and the covariation of trial type and task type by participant:

$$\begin{aligned}\text{ReactionTime} &\sim \text{TrialType} + \text{TaskType} + (\text{TaskType} : \text{TrialType}) \\ &+ (1 + \text{TrialType} \mid \text{RefWord}) + (1 + \text{TrialType} + \text{TaskType} \mid \\ &\quad \text{Participant})\end{aligned}$$

All p values were estimated using the normal distribution. Overall participants were faster to respond to thematic trials (M = 1771ms, SE = 74ms) than taxonomic trials (M = 2088ms, SE = 123ms), EST = 158.55, SE = 51.29, p < 0.01. Critically, participants were slower in switch trials (M = 1965ms, SE = 93ms) than in same trials (M = 1891ms, SE = 85ms), EST = -37.19, SE = 17.48, p = 0.03. The interaction between trial type and task type was not statistically significant, EST = -6.96, SE = 16.81, p = 0.68 (Figure 2).

	Mean Same	SE Same	Mean Switch	SE Switch	Mean Difference
Taxonomic	2044ms	122ms	2132ms	129ms	88ms
Thematic	1741ms	74ms	1801ms	81ms	60ms

Table 4. Mean reaction times and standard errors per condition (ms stands for milliseconds).

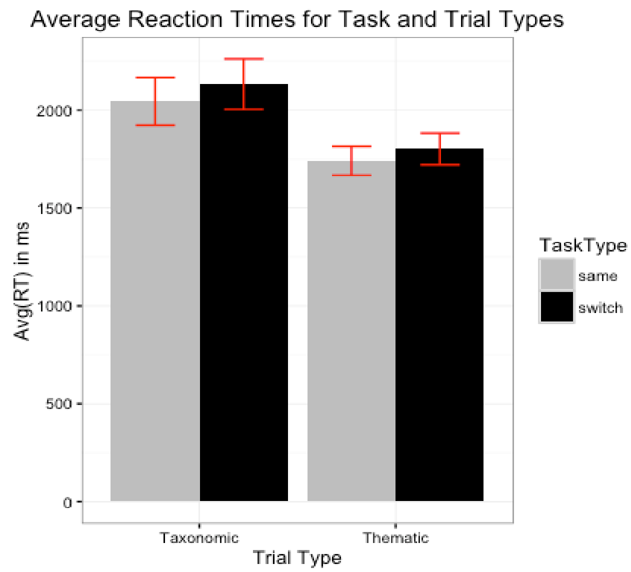

Figure 2. Average reaction times for thematic and taxonomic same and switch trials with 95% confidence intervals taken from the final model fit.

Graded Strength Analysis

A post-hoc analysis to determine if there was a relationship between the graded relationship strength of the word pairs and the switch cost was considered. However, examination of the distribution of the relationship strengths revealed a clear bimodal distribution (Figure 3), precluding such an analysis. For bimodally-distributed data, continuous analyses tend to reproduce categorical analysis results even if the within-group patterns are in the opposite direction, making the continuous analysis redundant and possibly misleading.

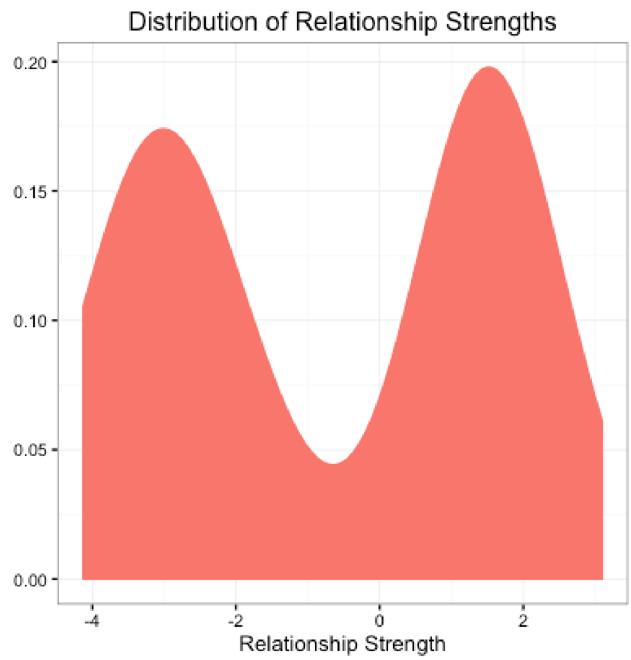

Figure 3. Distribution of relationship strengths for the 96 word pairs used in the triads switch cost study. Negative values indicate thematic relatedness and positive values indicate taxonomic similarity.

Interim Discussion of Triads Results

The presence of the switch cost is consistent with the predictions made by a dual-hub hypothesis. Regardless of the direction of the switch being made (i.e. from taxonomic to thematic or from thematic to taxonomic) there was a behavioral cost present. If taxonomic and thematic relations are represented within a single system, then there would be no reason to expect a consistent cost when switching from one kind of relatedness judgment to the other; indeed, there would be no switch involved. In contrast, if there are two systems, then a switch trial involves disengaging one system and engaging the other, which could produce the switch cost observed in this experiment. Moreover being that this was one of the first experiments to show a behavioral cost associated with switching between taxonomic and thematic relations in healthy college aged adults, it raised the question of whether this effect was specific only to this task or if it would generalize to other tasks as well.

Section 2.4. Experiment 2 - Oddball

Motivation

The primary motivation behind this task was to see if the switch cost observed in the triads task would generalize to a more complex task. Thus the oddball switch cost study utilized the *same switch* paradigm as employed in the triads switch cost experiment but the task the participants had to complete on a given trial was different. In this study participants had to select the “oddball” and/or the unrelated item out of a set of four items. In order to do so the participants needed to identify the dominant relationship (taxonomic or thematic) between three out of the four items while simultaneously suppressing the opposing relationship between the oddball and one of the other items. Moreover, the presence of a switch cost in this study would bolster the results of the triads switch cost study and provide more evidence for a dissociation between taxonomic and thematic processing.

2.4.1. Methods

Participants

32 participants were recruited from Drexel University (10 males and 22 females). The mean age of the participants was 20.8 years old (*SD* = 1.9). All participants were native English speakers or multilingual speakers who had learned English by the age of 6 years old. All participants provided informed consent and were compensated with course credit for their participation.

Materials

Trials for this experiment included the simultaneous presentation of four words. Three words were related either taxonomically or thematically with the final word related to only one of the other three in the opposite relationship. The word groups were based upon the definitions of taxonomic and thematic relations described above. Word triplets were normed through Qualtrics online survey services and Mechanical Turk. Mechanical Turk participants were expected to meet the following criteria:

1) Be a current resident of the United States of America
2) Either be a native English speaker or have learned English before the age of 5.
3) Primarily speak English at home and their place of employment
4) Have a high school education or higher.

The instructions for the survey were:

"Thank you for participating. In this survey you will be presented with a number of word triplets and asked to rate how well the words group together on a scale from 1 (Do Not Group Together At All) to 7 (Group Together Very Well). Using the radio buttons below each set select 1, 2, 3, 4, 5, 6, or 7 to rate how well the words group together. The word triplets may be grouped together based on co-occurrence in the same event or scenario, for example Motorcycle, Helmet and Tire or they may group together based on similarity, for example Palm Tree, Pine Tree and Maple. As you rate the triplets remember to base your rating on all 3 words together and not just a pair of words in the triplet. For example in the case of Motorcycle, Helmet, and Tiara. Although Tiara and Helmet are similar in that they are both worn on the head, the inclusion of Motorcycle makes it a bad grouping because a Motorcycle is not similar nor related to a Tiara.

Please use the full range of the scale (1, 2, 3, 4, 5, 6, or 7) in indicating your responses. Only the buttons below the word pair will work for rating the items. Please make sure to rate all the triplets in the survey, however if you are unsure of what the definition of a word is in a group you may skip it, though skipping a large portion of the survey may result in forfeiture of payment."

Word triplets were pulled from the original trial groupings of four words (made by adding an extra thematic or taxonomic item to the pairs normed for the triads task), so that every possible triplet of words was normed for how well they grouped together (for an example see table 5).

Triplet	Correct / Incorrect
EASTER, RABBIT, THANKSGIVING	INCORRECT
EASTER, EGG, THANKSGIVING	INCORRECT
RABBIT, EGG, THANKSGIVING	INCORRECT
EASTER, RABBIT, EGG	CORRECT

Table 5. Examples of triplets taken from trial grouping of EASTER, THANKSGIVING, RABBIT, EGG. In this example THANKSGIVING would be considered the oddball and any triplet including it would be considered incorrect.

Trial groupings were only included if the triplet of related words (correct trial grouping) had a mean normed rating of at least 0.5 points higher than the rest of the possible triplets for that grouping. In the cases where the correct triplet did not meet the inclusion criterion its grouping was discarded and the grouping in the opposite relation based on the same reference word was also discarded in order to keep the trial lists balanced. Further all oddballs and non-oddballs were also matched in terms of their length in letters and phonemes (obtained from the Speech and Hearing Lab Neighborhood Database, 2014), word frequency (obtained from the *Subtlex* US database for reference see Brysbaert & New, 2009), and orthographic neighborhood sizes (obtained from the *ClearPond* database see Marian et al., 2012) The norming criteria resulted in a final list of 64 groupings (i.e. 32 taxonomic groupings and 32 thematic groupings).

As in the triads switch cost experiment 4 lists were created consisting of two blocks each. Lists were counterbalanced so that each reference word was presented in its taxonomic grouping and its thematic grouping between blocks of a single list and in same (taxonomic to taxonomic dominant or thematic to thematic dominant) and switch trials (taxonomic to thematic dominant or thematic to taxonomic dominant) across the lists. Note that the term dominant here represents the correct triplet grouping within the trial (for example see figure 4). In sum there were 32 critical trials per block totaling 64 critical trials in a 2 (trial type: taxonomic vs thematic) by 2 (task type: same vs switch) with 16 trials in each cell of the design. Participants were randomly assigned to 1 of the 4 lists resulting in 8 participants completing each list.

Procedure

Participants began by filling out a brief background survey and then began the experiment. The experiment was run using the PsychoPy software. Groups of words were presented simultaneously to the participants. The participant was instructed to select the word that *does not fit with* the others by clicking on the word with the mouse. After each trial the participant was then presented with a cross in the middle of the screen, which they needed to click on in order to center their mouse and begin the next trial. After clicking on the cross there was a brief ITI of 500 ms before the presentation of the next trial. As was done in the triads task, at the onset of the experiment participants first completed 5 practice trials with feedback and then 5 practice trials without feedback, before the analyzed trials began. After completing the first block of trials participants were given the opportunity to break for a short period before beginning the second block. The first trial after the break was excluded from the analysis as it did not represent a same nor a switch trial (for reference see figure 5).

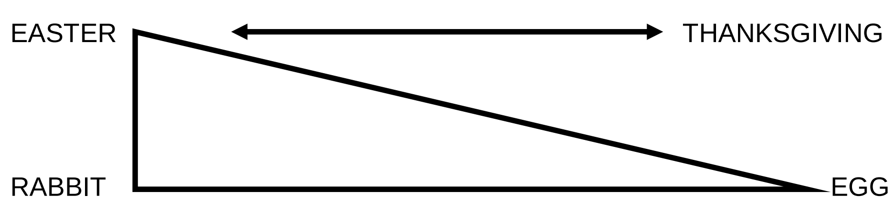

Figure 4. Example trial presentation with a taxonomic oddball and dominant thematic grouping. Lines indicate relationships and are included in this schematic but not in the actual trials.

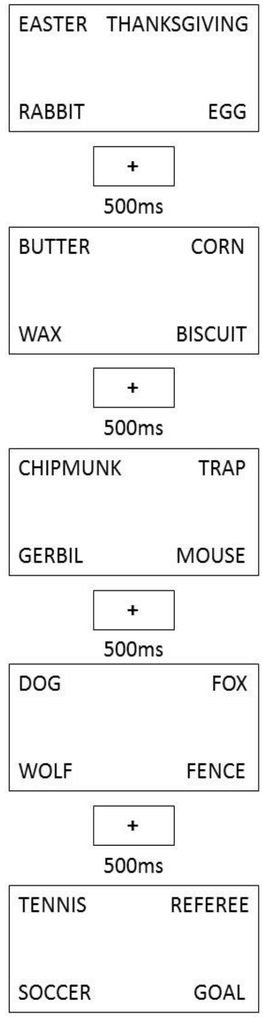

Figure 5. Example timeline of Oddball trials. Each box represents a single trial with between trial cross presentations and 500ms ITI. The first trial (EASTER-RABBIT-EGG) is a thematic trial and the second trial (BUTTER-CORN-BISCUIT) is a thematic trial as well. Thus the second trial is a thematic same trial. The third trial (CHIPMUNK-GERBIL-MOUSE) is a taxonomic trial and is therefore a taxonomic switch trial. The fourth trial (DOG-WOLF-FOX) is a taxonomic trial as well and is considered a taxonomic same trial. The last trial in the sequence (SOCCER-GOAL-REFEREE) is a thematic switch trial as it is a thematic dominant trial and the trial before was a taxonomic dominant trial.

2.4.2. Analysis and Results

Following from the triads switch cost study, data were analyzed using the statistical tools provided by R version 3.1.2 (R Core Team, 2014). Reaction times of incorrect trials and trials where the reaction time was less than 250 ms were excluded from the analysis. The subsequent trial after these trials were also excluded because if the participant got a trial wrong or hit the button before actually processing the stimuli, then it was assumed they did not understand the probed relationship and thus the subsequent trial would neither be a same nor a switch trial. Overall compared to the triads switch cost study accuracy on this task was much lower (M = 75%). The poorer performance on this task can be explained by the open-ended nature of the trials. Meaning that although the stimuli were built on the taxonomic and thematic word pairs from the triads task, the relation between the oddball and reference item may have pointed participants towards other types of relations among the 4 words within a trial. These exclusion criteria resulted in a total of 845 out of the original 2048 experimental trials (41%) being dropped from further analysis. Further, each participant needed to reach a minimum threshold of 3 analyzable trials per condition for their data to be included as anything lower could create issues when employing the model to analyze the reaction time data at the trial level. This resulted in the exclusion of 3 participants' data from further analysis (38 trials). Thus the final number of trial observations was 1165 from 29 participants. The data were analyzed using the same model that was used in the analysis of the triads switch cost study (for reference of the model specifications see section 2.3.2).

Overall participants were faster to respond to taxonomic trials (M = 5921ms, SE = 430ms) than thematic trials (M = 7026ms, SE = 475ms), EST = -554.93, SE = 221.09, p = 0.01. Critically and in line with the triads switch cost study, participants were slower in switch trials (M = 6727ms, SE = 471ms) than in same trials (M = 6188ms, SE = 358ms), EST = -274.51, SE = 135.99, p = 0.04. The interaction between trial type and task type was not statistically significant, EST = 131.35, SE = 99.86, p = 0.19 (Figure 6).

	Mean Same	SE Same	Mean Switch	SE Switch	Difference
Taxonomic	5781ms	401ms	6067ms	516ms	286ms
Thematic	6628ms	464ms	7440ms	545ms	812ms

Table 6. Mean reaction times per condition (ms stands for milliseconds).

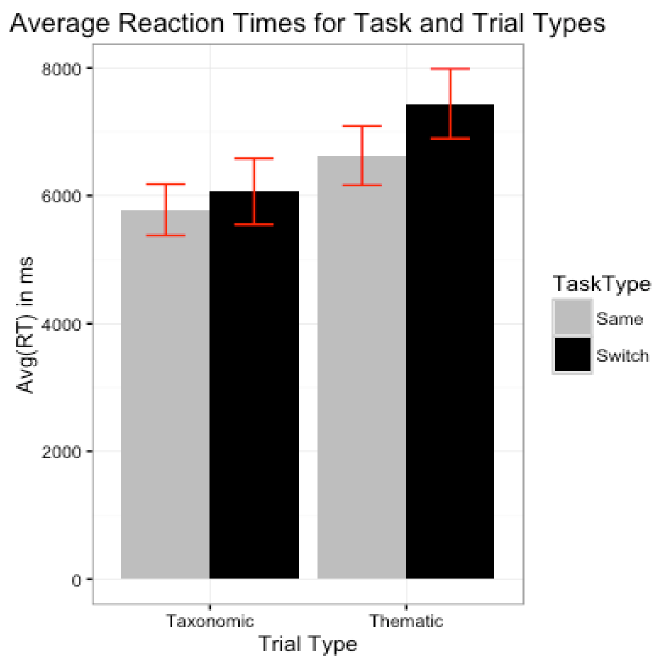

Figure 6. Average reaction times for thematic and taxonomic same and switch trials with 95% confidence intervals taken from the final model fit.

Interim Discussion of the Oddball Results

In line with the conclusions drawn from the results of the triads switch cost study, these results provide further evidence for a dissociation between taxonomic and thematic processing. This is evidenced by the presence of a switch cost when switching between the type of semantic processing (i.e. taxonomic or thematic) to complete a trial. These results therefore align with the results of the triads switch cost study, as again when presented with switch trials participants needed to switch the type of processing they were using in order to correctly identity the dominant relationship and select the item that did not fit. Whereas if there were only one system responsible for handling both relations then there would not have been any switch cost.

Section 3. General Discussion

This project had two distinct goals. The first of these goals was to provide a large set of publicly available taxonomic and thematic word pair norms as well as to provide a new way of norming for future studies on this topic. This was accomplished by norming the materials provided by three prior studies on taxonomic and thematic semantics in the same fashion as the norms for the triads switch cost study and then combining them resulting in a final set of 659 word pairs. A paper describing the norming methods and the two datasets was published in the Journal of Open Psychology Data (see Appendix A: Landrigan & Mirman, 2016) and the taxonomic and thematic word pair norms and individual participant rating data were deposited and are freely available in the Harvard Dataverse Repository (http://dx.doi.org/10.7910/DVN/FKTQ4C). These data have the potential to be used in future studies that investigate taxonomic and thematic processing as the data allow researchers to see the extent to which the pairs are either taxonomically similar, thematically related, share both relations or share neither of the relations. These norms could also be paired with pictures that have been normed for name agreement so that investigators can design studies not only using the written words but also the corresponding pictures (though the pictures should also be normed in terms of their similarity and relatedness, as they may invoke different semantic processing e.g Saffran, Coslett, & Keener, 2003). Furthermore, the second goal of this project was to investigate the organizational and processing mechanisms responsible for taxonomic and thematic semantic processing.

As discussed in the background section there are two current theories that make clear predictions about how these two types of relations are processed by individuals. The distributed plus hub model holds that although semantic features of concepts are broken down into their perceptual components a single amodal processing hub exists that processes both taxonomic and thematic semantics (Patterson et al., 2007). On the other hand although the dual-hub model agrees that semantic features of concepts are broken down into their perceptual components, it predicts that two distinct processing systems are responsible for taxonomic and thematic processing (Schwartz et al., 2011). Moreover the results of the triads switch cost study and the results of the oddball switch cost study fall in line with the predictions made by the dual-hub theory of semantic processing.

This was evidenced by the clear reaction time difference that was present when switching the type of semantic processing necessary to complete a trial, as regardless of whether participants were switching from taxonomic to thematic or thematic to taxonomic, they were slower to respond than when sequential trials were of the same relation (i.e. taxonomic to taxonomic or thematic to thematic). The presence of this reaction time difference when switching suggests that it took participants time to change over from taxonomic to thematic processing or vice versa from thematic to taxonomic processing. Although this could be due to multiple reasons including differing underlying neural mechanisms (i.e. ATL and TPC) needing to switch on and off, the present results do not require distinct neural hubs but do require distinct processing systems to switch between.

Looking at the triads task when choosing between the two competitors in the taxonomic trial participants needed to make feature to feature comparisons. This required them to hold both the features of the reference item and the features of the competitors in mind in order to judge their similarity and/or to determine if the items belong to the same category. Whereas in thematic trials participants needed to connect the reference item to the competitors in time and place in order to select the item that was most related to the reference item at the top of the screen. Thus when switching between trials the basic semantic comparisons that participants needed to make differed. This therefore could lead to the behavioral cost observed because participants needed to switch the cognitive processes involved in making these judgments. Further in the oddball study participants needed pick out the dominant relation amongst three out of the four items, whether it be taxonomic or thematic, while at the same time suppressing the link between the oddball and the reference item which the dominant triad was built around. Therefore when participants switched from one dominant relation type to the other it would have taken time to reactivate the previously suppressed relation in order to make the proper judgment required to select the correct oddball. Providing more evidence that the underlying cognitive processes needed to make these judgments differ, as if they relied on the same cognitive processes no switch cost would be expected.

For example a generic spreading-activation semantic network would not predict the observed switch cost because this type of network does not differentiate between taxonomic and thematic relationships (much like an associative network discussed in the introduction). Therefore the observed switch cost would not have appeared because on switch trials the processing requirements would not need to switch over as both taxonomic and thematic competitors would be active in both trials. Hence performance would not be slowed when switching between relationships because the same processing architecture would be required. On the other hand complementary but distinct systems are able to explain the switch cost, as on switch trials the processing system would need to change between taxonomic and thematic processing whereas on same trials the processing system would stay the same and in a sense prime itself to be used again resulting in quicker responses on same trials.

Moreover the results from these studies also fall in line with the prior developmental and aging work discussed in the background section (Blaye et al., 2006, 2007; Maintenant et al., 2011, 2013). Just as in those studies the current studies revealed a behavioral switch cost as well. However, the current study adds and builds to the evidence from the developmental and aging literature as it showed that even in healthy college aged adults there was a cost associated with switching from one relational type to another. Although this was not an issue of accuracy as in the developmental and aging literature, a clear reaction time cost was present in college aged adults.

Future studies investigating differences in taxonomic and thematic studies should try to address the neural mechanisms that underlie these processes as the present study cannot make any neural claims and is limited to only interpreting the results at a behavioral processing level. Studies utilizing the same switch cost paradigm could be paired with techniques such as transcranial magnetic stimulation or transcranial direct current stimulation in attempts to try and clarify the conflicting neural results. Further it would be interesting to see if long runs of sequential taxonomic or long runs of sequential thematic trials would give rise to larger switch costs when presented with the opposite relation and or if individual reliance or preference of taxonomic and thematic relations could differentially predict a participant's performance on a task such as this. For example although the results revealed that on average in the triads switch cost study participants responded quicker to thematic trials, it may be that individuals who rely more heavily on taxonomic relations may respond quicker on taxonomic trials, just as the relative activation of competitors in the eye tacking study performed by Mirman and Graziano (2012) predicted subsequent performance on a similarity judgment task.

Section 4. Conclusions

In summary this project provided a set of norms for future studies to utilize and provided behavioral evidence supporting a dual-system model of semantic processing, where there are separate and distinct cognitive processes responsible for making taxonomic and thematic judgments. Although as noted no neural claims can be made, this provides evidence to the fact that a behavioral cost appears even at an implicit level when switching between these two types of relations.

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Appendix A – First Page Landrigan and Mirman, 2016

Journal of open psychology data

Landrigan, J-F and Mirman, D 2016 Taxonomic and Thematic Relatedness Ratings for 659 Word Pairs. *Journal of Open Psychology Data*, 4: e2, DOI: http://dx.doi.org/10.5334/jopd.24

DATA PAPER

Taxonomic and Thematic Relatedness Ratings for 659 Word Pairs

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These data are comprised of taxonomic and thematic relatedness ratings for 300 target words paired with taxonomically related and/or thematically related words for a total of 659 word pairs. The pairs come from 4 prior studies and were normed through surveys provided online using Amazon's Mechanical Turk. Pairs were rated in terms of both their taxonomic similarity and their thematic relationship. The data are provided as comma-separated (.csv) and R data (.rdata) files and can be used to create new studies investigating taxonomic and thematic semantic processing.

Keywords: Semantics; Taxonomic; Thematic; Similarity; Related
Funding statement: This research was supported by a grant from the National Institutes of Health (R01DC010805) to D.M. and by Drexel University.

(1) Overview

Context

Collection Date(s)

September–November 2014 and June–July 2015.

Background

Understanding how taxonomic relations (based on feature similarity) and thematic relations (based on co-occurrence in events) operate in the mind has been a long standing topic of interest among cognitive psychologists. Investigators have used a variety of tasks to understand how these relations operate and coincide in the mind, including free sorting, forced choice categorization, similarity ratings, and semantic decision paradigms. Recently the neural organization and processing of taxonomic and thematic semantic memory has also become an increasing topic of debate among cognitive scientists [1, 4, 6]. To date however, there has not been a consistent quantitative definition of taxonomic and thematic relatedness. Feature overlap or biological taxonomy is often used to define taxonomic similarity. For thematic relatedness, some researchers have used latent semantic analysis while others have used their expert opinion and thus there has been a lack of consistency in terms of materials across studies [1–3]. This lack of consistency may be a possible reason for the conflicting results regarding the organization and neural mechanisms responsible for taxonomic and thematic processing [1, 2, 6]. In this dataset, word pairs were collected from four independent studies investigating differences in the processing of taxonomic and thematic semantics and re-normed by obtaining the strength of taxonomic and thematic relationships for each pair of words. This was done in order to provide the field with a common set of normed items for future research.

(2) Methods

Sample

Participants were recruited through Amazon's Mechanical Turk services. All participants were from the United States and were paid for their participation in the surveys (payment varied depending on survey length). Participants were limited to completing only one survey. Participant's responses were only included if they completed 90% or more of the survey, were from the United States of America and spoke English as their primary language. Responses from a total of 157 participants were included in the final data (85 females and 72 males). Ages ranged from 19 to 67 ($M = 34.8$, $SD = 10.63$). All but four participants were native English speakers. The four participants who were not native English speakers learned English by the age of 10.

Materials

The 659 word pairs found in this data set come from four studies conducted by independent research groups. The norming was done through a series of 12 online surveys